THE EURECA TELECOMMANDING CHAIN: EXPERIENCE WITH PACKET TELECOMMAND AND TELEMETRY SYSTEMS.

C. Müller, R. Bater
Logica Space and Communications Ltd., London, UK

E. M. Sørensen
European Space Operations Centre, Darmstadt, Germany

ABSTRACT

The European Retrieval Carrier (EURECA) was launched on its first flight on the 31st July 1992 by the Space Shuttle Atlantis. EURECA is characterised by several new on-board features, most notable Packet Telemetry and a partial implementation of Packet Telecommanding using an early version of the Command Operation Procedure (COP-1) protocol. EURECA has also very low contact time with its Ground Station, with a consequent high number of out-of-visibility on-board operations. This paper concentrates on the implementation and operational experience with the COP-1 Protocol and the effect the short ground contact time has on the design of the Commanding System. Another interesting feature is that the COP-1 is implemented at the Control Centre rather than at the Ground Station. The COP-1 protocol also successfully supported the mission during the Launch where commands were sent via NASCOM and the Shuttle.

Key Words: Packet Telecommanding, COP-1 protocol, Command Verification.

1. INTRODUCTION

The European Retrievable Carrier (EURECA) is a reusable platform supplying power, cooling, ground communications and data processing services to a variety of independently-operated payloads (ref 1). Fifteen experimental facilities are carried to support more than fifty individual experiments, most relying on the microgravitational environment. The operational altitude is 500 Km. The Operations Control Centre (OCC) is at ESA's European Space Operations Centre (ESOC) in Darmstadt, Germany. The primary groundstations are at Maspalomas in the Canary Islands and Kourou at French Guinea. During the deployment and retrieval phases contact is maintained via the NASA Communications Network and the STS.

At ESOC, operational data processing is carried out on the Eureca Dedicated Computer System (EDCS) that hosts the mission-configured Spacecraft Control and Operations System (SCOS) (ref 2) and the Eureca-Specific Software (ESS) applications.

The Eureca-A1 mission has characteristics differing quite considerably from those of missions hitherto supported at ESOC. One of these is the use of Packet Telemetry and Packet Commanding. Eureca is the first ESA application of Packet Telemetry and Commanding.

2. PACKET TELEMETRY AND COMMANDING

2.1 TELEMETRY

Eureca's telemetry is packetised according to standards based on a Recommendation of the Consultative Committee for Space Data Systems (CCSDS), ref. 3.

The Packet telemetry recommendation (ref. 3) uses two principal data structures, the source packet and the Transfer Frame, source packets being multiplexed within transfer frames. Each on-board source must label its data packets using CCSDS defined headers. The transfer frames are of fixed length, optimised for high-performance transfer to the ground. For Telecommand verification each Transfer Frame has attached a Command Link Control Word (CLCW) that is used by the COP-1 Protocol. The CLCW is essentially meant to be used in automated transmission/retransmission processes. Therefore, CLCW data must be delivered error free to the sending end of the Telecommanding system. The protocol information contained in the CLCW is such that it is not required that the Telemetry Transfer Frame rate match the Telecommand Block Rate. However, some minimum CLCW sampling rate must be established for the proper operation of the COP-1 protocol.

2.2 TELECOMMAND

Unlike the telemetry system, the Eureca telecommanding system has to support the old command standards (Ref. 4) and the new Packet command standard (Ref. 5). The reason for this is the way it has been implemented on board. Command decoders using the old standard have been used as a basis, but the extra services of the packet commanding have been built into the On-Board Computer (OBC). Thus when the OBC is nominally activated, the commanding system acts like a packet command system, using a subset of COP-1 of the standard (ref. 5). If the OBC is off, the old standard has to be used.

3. COP-1 PROTOCOL

NOTE: In this section, although the word COP-1 is used, EURECA has only implemented a subset of the COP-1. The EURECA terminology and services are not completely compatible with the latest issue of the CCSDS recommendation.

COP-1 is a closed-loop Telecommand Protocol that utilises sequential ("go-back-n") retransmission techniques to correct Telecommand Blocks that were rejected by the spacecraft because of error. COP-1 allows Telecommand Blocks to be accepted by the spacecraft only if they are received in strict sequential order. This is controlled by the necessary presence of a standard return data report in the telemetry downlink, the Command Link Control Word (CLCW). A timer is used to cause retransmission of a Telecommand Block if the expected response is not received, with a limit on the number of automatic retransmissions allowed before the higher layer is notified that there are problems in sending Telecommand Blocks. The retransmission mechanism ensures that:

- No Telecommand Block is lost
- No Telecommand Block is duplicated

  No Telecommand Block is delivered out of sequence

The COP-1 protocol has also an expedited service. This service is used for exceptional spacecraft communications. Typically, this service is required for recovery in absence of telemetry downlink (i.e no CLCW), or during unexpected situations requiring unimpaired access to the spacecraft data management system.

Figure 3.1 gives a simplified overview of the EURECA COP-1 Protocol.

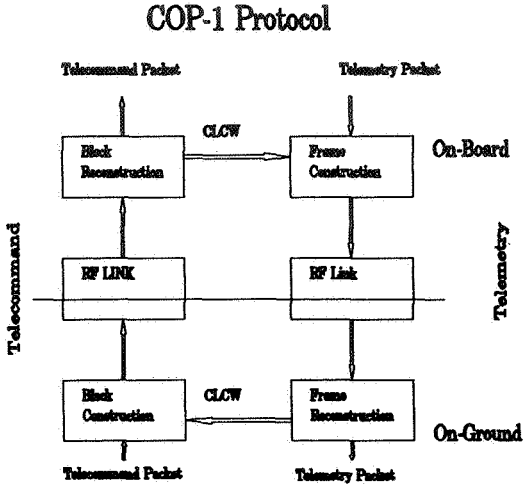

Figure 3.1 EURECA COP-1 Protocol

4. IMPLEMENTATION OF THE COP-1 PROTOCOL

The EURECA Commanding system only uses a small subset of the COP-1 services and the commanding system was designed before the COP-1 standard was available. In the event, it proved impossible to develop this general infrastructure equipment containing the EURECA standard and the COP-1 in the required time scale. It was therefore decided to use a Mark II Telecommand decoder (supporting the old ESA standard) and implement all the necessary packet block building and protocol execution in software within the spacecraft control system at the Control Centre.

Figure 4.1 gives an overview of the EDCS implementation of the COP-1 Protocol when commanding via an ESA Ground Station.

The basic principle is that all the additional packet block building and protocol execution associated with the Packet Telecommand Standard are performed within the spacecraft control system at the OCC. The ground network and station equipment is only used to transport these data structures from the control centre to the spacecraft.

4.1 COP-1 VIA NASCOM

For Eureca the possibilities exist to transmit telecommands via NASA facilities (NASCOM/MCC) and via ESA ground stations. The first is only needed during the launch and early orbit phase and retrieval. The latter is in addition needed for the routine phase. The commanding via

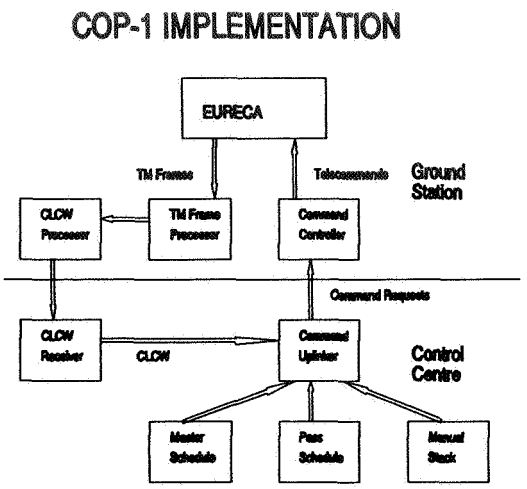

Figure 4.1 EURECA Implementation of the COP-1 Protocol

NASA facilities is complex, for two reasons: first the different NASA ground system for commanding. Secondly, the users required a command interface that looked the same as that for commanding via ESA stations (except possibly for response times); they require for example a similar manual command interface and automatic commanding; where real-time telemetry is available on-line they also require common verification.

Figure 4.2 gives an overview of the EDCS implementation of the COP-1 protocol when commanding via NASA.

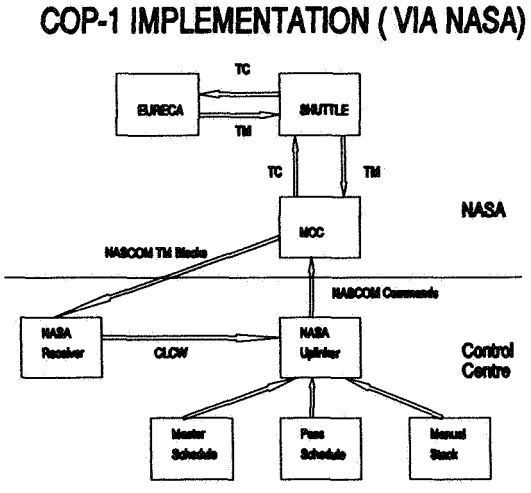

Figure 4.2 EURECA implementation of COP-1 via NASA

The same basic principles apply as commanding via an ESA ground station. The NASA infrastructure is only used to transport EURECA data structures from the control centre to the spacecraft.

4.2 CONSIDERATIONS FOR THE IMPLEMENTATION OF THE COP-1 PROTOCOL

The COP-1 protocol is only designed to provide the services between two COP-1 protocol machines one on-ground and one on-board. In terms of network layers the COP-1 protocol can by classified as a transport layer. The COP-1 does not provide an end-to-end transport service. It is the responsibility of the implementer to develop any required Higher Layer protocols using the underlying services of the COP-1 protocol. Additional protocols may also required when multiple sources on the ground are accessing the same COP-1 machine.

The COP-1 Sequence-Controlled Service is normally initiated by means of Service Directives. However in case of ground failures it may be necessary to include additional higher layer protocol elements to initiate the COP-1 services proper. This is also required to resynchronise between multiple ground users and on-board users. To allow EURECA to operate autonomously, EURECA executes commands from its on-board Master Schedule. To support the uplink of the Master Schedule EURECA has implemented a command insert counter which is reported in the Housekeeping Telemetry. This counter is used in operational procedures to restart the uplink of the Master Schedule in case of any ground failure.

4.3 OPERATIONAL EXPERIENCE WITH COP-1

There have been a number of occasion where the COP-1 protocol has successfully recovered an error. These cases all concerns link degradation, and involved the following circumstances:

1. During the Deployment phase with a bad RF link between the Shuttle and EURECA

2. During the Deployment phase where the EDCS did not receive a Command Acceptance Pattern (CAP) from NASA.

3. During ESA ground station passes where the spacecraft was configured with the wrong antennae.

4. During ESA ground passes where commanding was executed down to 0°

elevation (resulting in degradation of the telecommand and telemetry links).

5. During on-board antenna switch over.

6. When the OBC failed to allocate a Telecommand buffer (due to an OBC overload condition).

Although not all of the above cases were foreseen in the design of the COP-1 protocol (in particular case 2 and 6) the COP-1 protocol has always successfully recovered the error with a maximum of two retries. It is also important that during EURECA routine operations with a normal link budget the COP-1 protocol has never been in retry (i.e no transmission errors).

5. LOW CONTACT RATIO

5.1 MAIN DRIVER REQUIREMENTS ON COMMANDING SYSTEM

The majority of EURECA's operations are executed outside contact periods. Thus a command uplinked at time T may be time-tagged for execution at T + 10 Hours and so will be held on the on-board master schedule. The relevant necessary telemetry to verify the execution of this command might not be downlinked until T + 18 Hours, and subsequently processed to yield the final verification result at T + 19 Hours. This is illustrated schematic in figure 5.1.

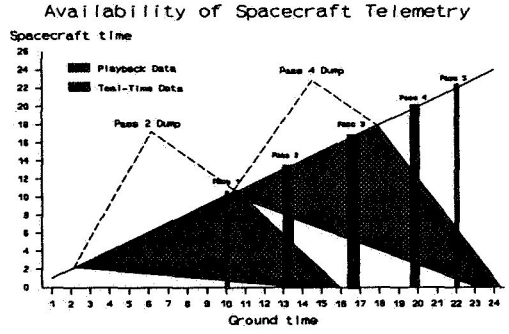

Figure 5.1 Relation between spacecraft generated data and the arrival at the OCC.

Figure 5.1 shows an example of five passes starting with a short pass followed by three long passes and ending with a short pass. During this pass sequence the on-board mass memory unit is dumped twice (pass 2 and pass 4). The first pass 2 dump telemetry is started to be routed to the OCC shortly after the end of pass 2 and terminates before pass 3. The routing of pass 4 dump telemetry is as shown delayed until after the last pass 5.

This delay result in three significant requirements on the ground system.

1. The Master Schedule's acceptance of time-tagged commands and their subsequent release to end users must be emulated. This on-ground maintained image of the on-board commanding provides the operations staff an indirect presentation of the on-board commanding activities and the status of verification.

2. Before each pass the commanding system shall prepare, an 'expected status of the spacecraft' using a defined subset of housekeeping parameters. This is prepared under the assumption that all commands not known to have failed have succeeded. As the telemetry parameters are received they are compared with the expected values, alarms being raised when differences are detected. This 'quick look' approach may detect command failures hours before traditional verification can take place and permit corrective actions to be taken within the same pass.

3. The commanding system must be able to verify commands using Real-Time Telemetry and Playback Telemetry. For EURECA playback telemetry will never arrive interleaved with real-time telemetry. However playback must arrive in chronological order, but the time of arrival is not significant.

5.2 COMMAND VERIFICATION

The basic mechanism for command verification is that all commands to be verified will have a verification window. The start of this window is the earliest time that the telemetry could be affected by the execution of the command and the end of the window is the time at which, if the command executes successfully, the telemetry must have been affected. If the verification criteria are met in the telemetry during the time window then the command is passed successfully; if the conditions have not been met at the end of the window then the next telemetry received decides pass or fail of the command.

For EURECA the Command Verification is a four stage process consisting of:

1. Uplink verification using the Command Link Control Word (CLCW). This cannot be applied for commands executed from the master schedule.

2. Verification of delivery at on-board destination using the end user generated Acknowledgement packets.

3. Execution Verification using special EURECA Report Packets.

4. Execution Verification using the Housekeeping Packets.

Figure 5.2 illustrates the EURECA verification concept.

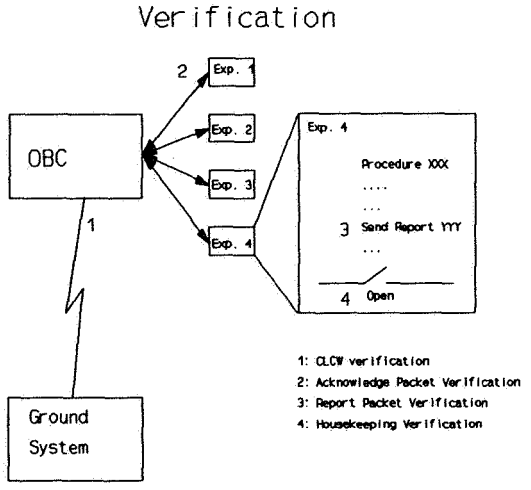

Figure 5.2 Verification

Command verification is therefore described by a vector, rather than a simple success/fail indication. Thus an example; could be 'uplink successful', acknowledged in real time', report packet received', 'housekeeping confirmation not yet available'. Some 26 such combinations are possible. Command verification also involves processing of various special packets associated with commanding, namely Acknowledge, Report and Exception packets, as well as traditional verification based upon changes in telemetry parameters. These may be found in real-time Telemetry and/or Playback Telemetry, which arrives at the OCC at different times.

6. LESSONS LEARNED

The following lessons have been learned about packet telemetry and telecommand systems from development of the Eureca spacecraft control system and operations:

6.1 COP-1 PROTOCOL

1. The COP-1 protocol has proven to be very reliable and is able to recover transmission error with minimal operational impact.

2. It is possible to implement the COP-1 protocol at the Control Centre using existing infrastructure such as the ESA MARK II Telecommand Controller and the NASCOM Remote Command Facilities

3. The design of the Control Centre must consider end-to-end protocols and provide elements that make it possible to recover in case of ground failures. The design must also consider the infrastructure to be used.

4. Introduction of Packet Telemetry and Telecommand is a major step towards standardisation of on-board and ground systems. To fully archive this goal it will be necessary to define standards governing end-to-end protocols such as File Transfer Protocol that are required to maintain on-board Master Schedules, and to support on-board software maintenance.

5. The distribution of protocol handling between the Ground Station and the Control Centre has to be considered taking into account the mission requirements. In the EURECA case where commanding is via ESA ground stations and via NASA it is desirable to implement the protocol at the control centre. This implementation also allows the COP-1 to recover in case of ground link errors. In other cases it might be considered to close the COP-1 protocol at the Ground Station. This might be attractive if commanding is considered time critical because all time critical functions are concentrated in the front-end Ground Stations. This is particularly true for the closed-loop operations of the COP-1 protocol.

6. It is not recommended to make the uplink protocol transparent to the operational staff. They require full visibility of the status of the uplink process including the status of the retry process. This is important because considerable uplink delay may be introduced when COP-1 protocol performs retries.

6.2 LOW CONTACT RATIO

1. The expected status is proven to be very useful. It gives the operational staff a prewarning and often triggers an emergency dump of on-board stored telemetry necessary for further investigation of the problem.

2. The EURECA verification implementation is based on one verification window per command. However this window can be closed by the arrival of any Telemetry Packet. This has caused problems because some on-board users have problems maintaining time synchronisation with the OBC and their local clock have therefore drifted into the future. The arrival of a packet with future time causes verification windows for other commands be falsely closed. It should therefore be considered to make the closing of the command verification window telemetry packet specific.

7. CONCLUSION

At the time of writing (October 1992) EURECA has been successfully supported by the Control Centre for 3 months. During this time the EDCS has successfully received and processed over 10 million telemetry packets and over 60000 commands has been sent. The COP-1 protocol has proven to be very reliable and given the operational staff much confidence in the EURECA commanding system.

The low contact ratio for EURECA has proven not to be a major problem. The functions provided by the EDCS gives the operational staff sufficient information for quick assessment of the status of the spacecraft during the short passes.

8. REFERENCES

1. Andresen, R.D. and Nellessen, W. "Eureca in the Columbus Scenario," 1988, Space Technology 8, 45

2. Kaufeler J-F and Mazza C., "A New Generation of Spacecraft Control System - SCOS," 1988, ESA Bulletin 56.

3. Consultative Committee for Space Data Systems, 1984,'Recommendation for Space Data System Standards: Packet Telemetry', "Blue Book".

4. PCM Telecommand Standard ESA PSS-45 Issue 1 April 1978

5. Consultative Committee for Space Data Systems, 1986, 'Recommendation for Space Data System Standards: Telecommand, Part-2: Data Routing Servive, Architectural Specification', "Blue Book".